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Stand damage when harvesting timber using a tractor for extraction

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Abstract. Damage to the remaining stand is an unavoidable consequence of thinning operations. The different machines used for timber extraction differ in the level of damage of trees they cause, mainly through wounds to the bark and cambium which can make a substantial impact on the remaining trees. Three different methods of timber harvesting with a chainsaw were analyzed: the short wood system (SWS), the long wood system (LWS) and the full tree system (FTS) in which an agricultural tractor is used for timber extracting. All systems were analyzed in stands containing three different age classes: 2nd (21–40 years), 3rd (41-60 years) and 4th (61–80 years). The level of damage to the remaining stand was assessed considering the percentage of trees exhibiting wounds (scratched bark and/or damage to the cambium) to calculate an index of stand damage (WDI) which incorporated the volume of harvested timber per hectare. The SWS produced the lowest damage to trees in stands of all age classes: average 5%, with the less damage in the oldest stand. After using the LWS, 9% of trees were wounded; in this method there was no statistical difference in frequency of wounding across all the analyzed stands. The highest level of damage was incurred after the FTS, causing 11% of trees to be injured. In stands of the 2nd age class, the method of timber harvesting had no statistically significant effect on the amount of wounding endured. The WDI was lowest in SWS: 0.08, higher in LWS: 0.15 and the highest, 0.23, when FTS was applied.

Key words: tree damage, Scots pine stands, forest operations, timber harvesting methods, extraction by tractor

1. Introduction

Modern timber harvesting technologies are based on the use of multifunctional harvesting machines, with a number of advantages in the fields of ergonomics, economics and environmental protection of the forest. Various authors estimate that there are no more than 200 such machines currently operating in Poland (Skarżynski and Brzózko 2010), harvesting no more than about 4 million m^3 of wood. There has been a significant increase in the number of forwarding machines (forwarders with trailers attached to agricultural tractors) being used. In the process of machine harvesting, chainsaws continue to be used (midfield method), helping to increase efficiency and reduce costs (Mederski 2006). In terms of pine tree harvesting in the country, the agricultural tractor is most commonly used, adapted to forestry work by aggregating various processors (Athanassiadis 1997; Stańczykiewicz et al. 2011) or self-loading trailers for extraction. In this study, the agricultural tractor was used to perform both skidding for processes based on the long wood system and full tree system, as well as for forwarding in the short wood system with a trailer attached to the tractor.

The hypothesis proposed is that the size of the harvested timber when thinning stands significantly affect

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the amount of damage to the remaining trees – the longer and wider the assortments, the greater the probability of damage. This is especially true when the logged wood has to be transported by performing a large number of turns in dense tree stands.

2. Research subject

The study was conducted in the Toruń Regional Directorate of the State Forests National Forest Holding, the Zamrzenica Forest District and Lnianek Forest in pine stands of 2nd, 3rd and 4th age classes while performing early (II age class) and late (III and IV age classes) thinning.

Logging was carried out in all study plots using manual-machine technology with tractor extraction using the following three methods:

1) short wood system:

phase: chainsaw tree felling, stump debarking, delimbing with an axe, or a chainsaw in older age classes, bucking stems at the stump with a chainsaw,

phase: forwarding with an Ursus C-360 agricultural tractor and trailer, stacking log piles at road side;

2) long wood system:

phase: chainsaw tree felling, stump debarking, delimbing with a chainsaw,

phase: whole log hauling using the Ursus C-360 agricultural tractor - hauling, bucking, stacking log piles at road side;

3) full tree system:

phase: chainsaw tree felling, stump debarking,

phase: skidding the trees using an agricultural tractor,

phase: delimbing and bucking with a chainsaw, stacking at road side.

During the development of methods to assess damage to trees and soil, the experiences of researchers in the Department of Forest Utilisation of Poznań University of Life Sciences were used, as well as the American concepts of conducting research in this field (Meyeretal., 1966). Sample plots of 50 × 50 m (0.25 ha) were established. Logging was carried out in plots slightly larger than the study area, surrounded by a buffer zone of several meters to prevent the distortion of study results from the logging methods used in adjacent sites. Four meter wide skidding trails were located at 30-35 m intervals. They were laid out through the middle of the plots and between them. The stand was assessed before and after logging. The number of damaged and destroyed trees was specified, indicating the location of the damage and depth of the wounds (bark scratches, cambium damage and damage to wood fibers). The damage was categorized according to the respective classes (tab. 1), which allowed the percentage of damaged trees and a weighted coefficient of tree damage (*W*) to be calculated,

$$W = \frac{\sum_{R=1}^{9} I \times R}{N},$$

where *I* is the number of damaged trees in the study plot, *R* the tree damage class, and *N* the total number of trees in the study plot after thinning.

When more than one damage class was identified on one tree, the more serious damage was recorded. In order to take into account the volume of harvested wood the weighted stand damage index (WDI) was calculated – as proposed by Meyeretal (1966), and popularized in Poland by Sosnowski (1999),

$$WDI = \frac{\sum_{R=1}^{9} I \times R}{N \times C} \times 1000,$$

where *I* is the number of trees with damage in a given damage class in 0.25 hectares of the remaining tree stand, *R* is the numerical value of the damage class number, *N* is the number of remaining trees in 0.25 hectares, and *C* is the number of harvested wood from 0.25 ha area.

The standard deviation was calculated for each logging method for the weighted coefficient of tree damage and the weighted index of damage to the remaining trees in the stand.

Using the Chi-square test, the frequency of damage observed among the different logging methods was compared. The same test was used to compare the differences in the frequency of damaged wood using the same logging method in stands of different age classes.

3. Results

Damaged trees were observed for all logging methods and in all age classes. Damage occurred on all parts of the trees. During the study, damage was observed in the tree crowns, on trunks, and the roots of the remaining trees (fig. 1). Broken limbs and smaller branches were damaged in tree crowns. One tree in IV age class was damaged due to having been significantly bent.

Tree trunks were found to be frequently damaged. As many as 58.6% of all the damage was due to bark scratches on the trunk. A relatively frequent type of

Table 1. Tree damage classes

Damage class	Damaged part of tree		Damage type
1	bark	Trunk or root neck	bark scratch
2	bark	roots	bark scratch
3	cambium	Trunk or root neck	scratched bark, opened or damaged cambium
4	cambium	roots	scratched bark, opened or damaged cambium
5	wood	Trunk or root neck	wood fibers wounded
6	wood	roots	wood fibers wounded
7	tree	bent	slightly bent tree with opportunity for further growth
8	tree	bent significantly	tree bent significantly with little chance of good development
9	tree	damaged	broken or pulled-off

damage, with 24.3% of occurrences, was the open cambium on tree trunks. Roots were also observed to be damaged, with wounds of varying depths, which were also noted on the stem surface.

The depth of a wound is critical for predicting the prognosis of the damaged trees because the extensive exposure of wood fiber contributes to a high risk of infection by pathogenic fungi. In this study, the wood fibers of tree trunks were damaged 33 times, representing 12.5% of all observations.

Although the most intensive thinning occurred in III age class stands, most tree damage was observed in the youngest age class stands studied. As the number of trees growing in a test plot decreases, so does the number of damaged trees (tab. 2). In II age class plots, with 621 trees remaining in the test sites, trees were damaged on average 53 times for all three studied harvesting systems. Significantly fewer trees were damaged in III class age stands, where with 370 trees remaining, damage was sustained approx. 26 times. The least amount of

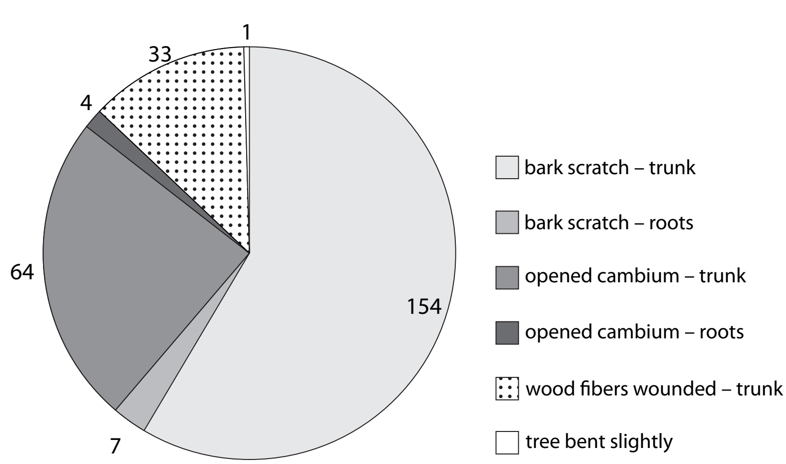

Figure 1. Number of trees with damage in all analyzed stands

Table 2. Tree damage in the analyzed forest operations

Age class of stand	Damage characteristics	Method of timber harvesting				p (χ^2)
		SWS	LWS	FTS	mean	
II	Number of trees with damage	40	61	59	53,3	0,119
	Number of remaining trees (including trees with damage)	602	636	626	621,3	-
	Ratio of trees with damage to number of remaining trees (%)	6,6	9,6	9,4	8,6	-
III	Number of trees with damage	14	29	34	25,7	0
	Number of remaining trees (including trees with damage)	472	373	265	370	-
	Ratio of trees with damage to number of remaining trees (%)	3,0	7,8	12,8	7,9	-
IV	Number of trees with damage	2	6	18	8,7	0
	Number of remaining trees (including trees with damage)	108	103	97	102,7	-
	Ratio of trees with damage to number of remaining trees (%)	1,9	5,8	18,6	8,7	-
	p (χ^2)	0,001	0,322	0,004	-	
All stands	Number of trees with damage	56	96	111	87,7	
	All remaining trees	1182	1112	988	1094	
	Ratio of trees with damage to number of remaining trees (%)	4,7	8,6	11,2	8,2	

Table 3. Weighted stand damage coefficient *W* and weighted stand damage index *WDI* values after using different methods of timber harvesting

Coefficient	Method of timber harvesting		
	SWS	LWS	FTS
W ± std deviation	0,08±0,06	0,15±0,08	0,23±0,03
WDI ± std deviation	8,91±4,82	22,28±1,64	41,41±37,22

damage noted after harvesting was in the oldest studied age class, with an average of less than 9 times with 103 trees remaining in the study plots.

The percentage of damaged trees by harvesting system was assessed in relation to the number of trees remaining in the study plots after harvesting and extracting. The smallest proportion of damage occurred with the short wood system. The share of damage with the long wood system was 8.6% and, therefore, was similar to the average of 8.2% for all three methods. The full tree system caused the greatest damage, with as many as 11.2% of all remaining trees sustaining damage.

The probability of causing damage presented in table 2 indicates a highly significant difference between the values obtained for III and IV age classes ($p<0.01$). There were no differences found between the frequencies of damage for II age class ($p = 0.119$). The values obtained with regard to the probability of damage occurring while using the same harvesting system but in different age class stands indicates a highly significant difference in the case of using the short wood system and full tree system: $p = 0.001$ and $p = 0.004$, respectively. However, no significant difference was found in the frequency of tree damage among different age classes when using the long wood system ($p = 0.322$).

The effect of the harvesting systems tested while using an agricultural tractor for skidding was expressed by a weighted coefficient of tree damage W. The higher the value of W, the stronger the negative effect of the system. The lowest coefficient values W were for the short wood system ($W = 0.08$), medium values for the long wood system ($W = 0.15$), and the highest ($W = 0.23$) for the full tree system (tab. 3).

Similar results were found in the case of the index of tree damage to the remaining trees in the stand (*WDI*), where the harvesting system and intensity of maintenance activities - early and late thinning - can be verified because the formula takes the harvested volume into account (tab. 3). Even though tree stands may be of equal age and form one division, they often differ in terms of stand density and tending needs. For this reason, more intensive cutting may be needed in some parts of the stand than in others.

WDI values vary depending on the logging methods used. In all three tree stand age classes, the short wood system had the smallest negative effect on the remaining trees. The long wood system resulted in tree stand damage at a *WDI* level of 22.28. The full tree method caused the most damage in terms of wounds and the amount of wood obtained. The *WDI* index in this case was 41.41, differing significantly from the values obtained with the remaining harvesting systems.

4. Diuscussion

Comparing the results of tree damage presents some methodological difficulties (Giefing 1995, 1999; Sowa et al. 2008). The existing systems of classifying tree damage differ both in terms of registering damage on different areas of the tree (root, neck and trunk, and crown), as well as due to their cumbersome use and applied coefficients (Giefing 1997; Suwała 2000; Gil 1999, 2000; Karaszewski 2004, Stańczykiewicz 2011). The least difficult is to compare the percentage of damaged trees in the remaining stand. In Zastocki (2003 a, b), in uncut stands where the assortment system (using short wood) of logging takes place, the share of damaged trees was on average 11.8%, whereas the long wood system damaged an average of 13.5% of trees. These figures are significantly higher than those obtained by the authors of this study (4.7% for the short wood system and 8.6% for the long wood system). However, Giefing (1994), in examining II age class tree stand damage after skidding with an agricultural tractor, found that only 2.2% of the remaining trees were damaged. The reasons for these differences may depend on such factors as employers' skills, the season of the timber harvest, as well as the skidding equipment used. In their summary of 10 years of studies at different research centers, Sowa and Stańczykiewicz (2007) present a wide variety of results obtained on the extent of tree stand damage and damaged saplings. These authors report levels of tree damage varying from 0.8% to more than 85.0%.

The available research results show that an important factor influencing the degree of tree damage is the length of the harvested assortment. According to Erler (2005), the average ratio of damage for harvesting short wood, logs (up to 2.5 m) and the entire trunk is respectively 1: 2: 5. This means that it is better for the stands to process the wood on site and in the shortest possible assortments (Erler 2005). This study also showed the least damage (4.7%) occurring with the short wood system. Assuming this level of damage at 1, the long wood system achieved 2 (8.6%), and the full tree system 2.5 (11.2%). In Stańczykiewicz's study (2003), damage to trees using the assortment method (short wood) is also smaller than with the long wood system.

These results are consistent with the views of most scientists. Paschal (1999) assesses the long wood system as practically non-recommendable because of issues related to protection of the forest environment, whereas the assortment system offers the greatest protection to forest ecosystems. Suwała (1996) postulated the gradual elimination of dragging and skidding by tractors. The research of Grodecki and Stempski (2005) confirmed that most of the trees are damaged with the use of a trac-

tor for hauling, especially when an agricultural tractor is used in tree stands with no access to the network of logging roads.

The full tree method proved to contribute to the greatest amount of disturbance to the remaining stand. This method is the most disadvantageous not only because of environmental protection requirements, but also due to the cost of harvesting (Porter, 1998). This is consistent with the position of Barzdajna et al. (1997), who state that the less valuable wood and tree remains should be left in the forest according to forest protection requirements. A similar opinion on the full tree system was voiced by Pilarek and others (2005).

The statistical analysis of the research presented here produced interesting results:

No differences were obtained in the incidence of damage to II age class stands regardless of the logging system used.

No significant differences were found in the frequency of tree stand damage using the long wood system among the different age classes of stands.

In the first case, the tree density of II age class stands was so high that numerous collisions occurred between the harvested and extracted assortments and remaining trees, regardless of the logging system used. Additionally, the tree stand was still in the early stages of development, so that the harvested trees were much smaller in size than in the older age classes (classes III and IV), therefore the differences in the lengths of short and long assortments were smaller. Regardless of the logging system used, a similar level of damage was observed (8.6%) in the youngest age class stands.

In the latter case, tree density was also the decisive factor for the remaining trees in the stand. It should be noted that this phenomenon (lack of difference in the frequency of damage in stands of different age classes) occurred regardless of the fact that long assortments in IV age class tree stands were approx. two times longer than the long assortments in II age class stands. Using the long wood system in stands of different age classes caused damage at a similar level (8.6%).

In the remaining cases, statistically significant differences were found in the frequency of damage. The short wood system achieved the best results in the oldest IV age class (contributing to the smallest number of defects). Meanwhile, the full tree system caused progressively more damage with the increasing stand age. This is indicated by the ratio of the number of damaged trees to the number of remaining trees (tab. 2).

Using various factors to assess the impact of a given harvesting system on the forest environment has both positive and negative consequences. Using the *W* coefficient and *WDI* index allows us to assess the studied harvesting technologies also in terms of the damage resulting to trees, and to take other factors into account, such as the volume of wood obtained from the harvested stands. The literature, however, presents yet other factors for tree, tree stand, and sapling damage (Stańczykiewicz 2003, 2006, 2011). The different methodologies make it difficult to compare research results, often only allowing for the observation of trends exhibited by the different technological processes. We agree with the constative statement expressed by Sowa and Stańczykiewicz (2007), of the necessity to develop a universal methodology to assess the damage resulting from logging in the forest environment.

5. Conclusion

The smallest damage to tree stands in all age classes were observed when using the short wood system. At the same time, this method resulted in the lowest frequency of damage in the oldest age class studied.

The lowest level of damage occurred with the use of the short wood system, which is exhibited by the percentage of damaged trees (5%), the value of $W = 0.08$ and the *WDI* value= 8.91.

Applying the long wood system caused a similar level of damage (9%) in all age class stands analyzed. The *W* coefficient with the long wood system was higher than the short wood system, resulting in a value of 0.15 and a *WDI* value of 22.28.

The full tree logging system caused the highest incidence of damage to the remaining trees: 11%. The value of the *W* coefficient, also the highest in the full tree system at 0.23, indicates a higher level of damage to trees than the rate expressed as a percentage. The *WDI* value for this method was 41.41.

The statistical analysis showed no effect of the harvesting system on the level of damage to trees in II age class, but the systems used had an impact on III and IV age class stands.

There were no statistically significant differences in the level of damage to trees in the age classes analyzed using the long wood system.

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